Hoist by their own petard: The constraints of hierarchical models

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Abstract: In the context of the motor skill literature on observational learning and hierarchical skill structuring, Byrne & Russon's findings call into question their standpoint that great apes imitate the behaviour of role models at the programme level. The authors impose a hierarchical model on their observations without properly considering alternative explanations. One such possibility, which stems from a constraints perspective that they dismiss, is put forward.

Our major concern with Byrne & Russon's (B&R's) target article is their *a priori* acceptance of a single model – a hierarchical skill model – as a framework for their observations. Their only justification seems to be that the organisation of the behaviour observed is "simply not well described as linear and chain-like" (sect. 2.2, para. 10). They dismiss potential alternatives in a rather cavalier fashion, stating, for example, that "it is highly implausible, however, that the constraints of the environment would be so tight that every animal would end up with the same hierarchical structure, yet so weak that the fine details of the techniques are highly variable between individuals" (sect. 2.4, para. 2). Our critique will focus first on the hierarchical model; then we will argue that B&R's dismissal of explanations based on the concept of *constraints* was rather premature.

Hierarchical modeling. The fact that we, as external observers, can describe and deconstruct behaviour into hierarchical units is no guarantee that the actor organised its behaviour hierarchically or that the behaviour was learned in a hierarchical fashion. Given that the motor skill literature has much to say about the hierarchical structuring of behaviour, also in the context of observational learning, it is surprising that B&R do not at least make reference to it. In this literature the origin of such structuring is often viewed in a similar way, that is, it is assumed that the lower levels of the hierarchy are established first and serve as the basis for integration at superordinate levels. This proposed order of establishment of such levels has been called into question, however, in at least two studies (Kohl & Shea 1992; Pew 1966). In a replication of Pew's earlier experimental laboratory work, Kohl and Shea for example, coupled observers to novice subjects required to learn a cursor matching task. Their findings led them to conclude that a "first-person direct perspective on sensory feedback and knowledge of results was not critical for attaining open-loop and hierarchical control" (p. 257). Kohl and Shea claim that their data support the notion that subjects may choose appropriate response/control schemes without actual practical experience, a standpoint that was suggested earlier by Martens et al. (1976). If this is the case, their findings might easily be subsumed under what B&R call "priming" rather than imitation. A similar interpretation might then also account for the feeding behaviour of baby gorillas. After all, the babies, throughout their developmental period, are confronted daily with the same *expert* model demonstrating appropriate response/control schemes. Having been primed in this way, they are free to experiment – at least within the bounds of the prevailing constraints.

Alternative explanations. In view of this critique of B&R's interpretation of the data, we will now present an alternative interpretation, arguing that the concept of constraints is much more powerful than B&R admit. A constraint on action is defined as any reduction in the range of possible configurations of the movement system. B&R mention environmental constraints only, but constraints can also originate from the task and from the animal (cf. Newell 1986). Constraints relevant to mountain gorillas, for example, are physiological characteristics of the teeth and gut that constrain the choice of food; biomechanical characteristics such as uni- and bi-manual dexterity and characteristics of specific food that constrain food manipulation such as spines and stings; information available from models pointing out alternative behavioural possibilities; and ambient conditions such as season, time of day, gravity, and so forth. From this perspective, models serve mainly as social facilitation. They can increase the *likelihood* of certain behaviours, but they do not *prescribe* behaviour. In other words, they act as informational constraints influencing *what* to do, but not *how* to do it. The latter needs to be filled in by individual experience.

The interactions between all extant constraints determine the possible patterns of coordination and control for an organism engaged in an activity. Note, however, that the confluence of constraints does not necessarily limit the actor to a single solution to a task, as B&R seem to suggest. Rather, by making certain behaviours impossible while influencing the efficiency and optimality of others, interactions between constraints determine both the range of possible solutions and the likelihood of each solution. Furthermore, constraints act more severely on behaviour at a global scale of description than on the details at a local scale of description, which are left relatively free. In short, the probability distribution ensures that the behaviour of all animals is channelled toward only a few solutions; within each of these solutions, behaviour across different animals will cohere globally but differ locally.

Both these characteristics are consistent with the data B&R report (i.e., 70–80% of the apes converge to the same global solution of preparing food), although local details vary widely between individual animals. The 20–30% discrepancy is consistent with a constraints perspective, but seems inexplicable from an imitation standpoint.

What is needed to test either explanation is an analysis of the learning process in young apes. Unfortunately, B&R do not report any data on the learning process *per se.* They have analysed the *product* of social learning in terms of a hierarchical structure of goals and subgoals, but it is at the level of the learning *process* where support is to be found for either a hierarchical or a constraints model. However, even with adult data, critical questions arise. If separate, noninteracting groups of mountain gorillas have the same feeding techniques, for example, would this not support the constraints model?

Toward a microanalysis of imitative actions

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Abstract: We outline a view of imitative behaviour as largely internally driven and discuss, based on experimental research, the distinction between program versus action level imitation, the role of organismic constraints, observational learning as vicarious exploration, and imitation as selection in speeded response paradigms.

> If one compares the movement imitated with its imitation, it is the integrated movement-melody of each which stands forth as being the common element; a photographic reproduction of the separate movements involved is never found. (Koffka, 1935, p. 308 f.)

Imitative behaviour has all too often invited the equivalent of a naive realist interpretation of perception, in the sense that an exact copy of the model behaviour is expected. Like perception, however, imitation always points to the cognitive capabilities of the imitator as well as to the model. Thus, Byrne & Russon's (B&R's) anchoring of their analysis of primate imitative behaviour in the

capacity for flexible, hierarchical action planning is a sensible starting point for clarifying the contrasting views in current primate research. In addition to hierarchical organization, the modularity and selectivity of sensory and motor processes have become major themes in neuroscience, and to capture the richness of imitative behaviour, these phenomena, too, require consideration. Also, more microanalytic (e.g., kinematic and chronometric) approaches have come to prevail over pure observational methods, and a major goal of current imitation research is to elucidate the interactions between the multiple sensory, representational, and motor preparatory processes involved in imitating even such simple actions as pointing to or grasping a glass of beer. Examples from our research relate specifically to points made in the target article and illustrate this approach.

Action level imitation? A close match in kinematic details between mimic and model may rely as much on structural organization as higher (or "program") level imitation does. Human subjects were asked to reproduce accurately a sequence of smooth lateral deviations of a cursor on a monitor (Vogt 1991; Whiting et al. 1992) – an apparently prototypical case for "action-level" imitation. Instead of producing stereotyped sequences of increasing length, however, subjects initially reproduced a small number of global characteristics of the cursor movement (such as its centering around a midpoint and an alternation of right- and leftward movements) before any fixed sequence emerged. Thus, even simple pattern learning appears to involve the extraction of complex features rather than the formation of linear associations. Primates are simply too clever to act as videorecorders. Accordingly, rather than contrasting program- and action-level imitation as distinct faculties, we interpret the (limited) capacity of human primates for near-exact copying as a consequence of their increased cognitive abilities, including a specific, quantitatively and temporally enhanced capacity to recognize and respond to the mimic and gestural behaviour of their conspecifics.

Organismic constraints. Near-exact copying may in some situations rely on shared organismic constraints between model and imitator rather than on sensory processing. Even after more than 100 reproductions of an artificially composed rhythmic pattern, subjects systematically deviated from its isochronic temporal structure, whereas their reproductions of a more natural, non-isochronic pattern were nearly perfect (Vogt et al. 1988). Thus, the use of artificial models (e.g., video animations) can help uncover apparently imitative behaviour resulting from shared motor control principles.

Observational learning as vicarious exploration. Like B&R, we were originally skeptical about observational learning as an aid to motor skill acquisition, particularly when an exploration of the medium of a skill (such as the mechanical properties of a racket) is required, but a recent experiment (Vogt 1996a) has made us more optimistic. The task involved a biphasic movement of the pivot of a pendulum along a linear track, and mastery of this task required precise (procedural) knowledge of the pendulum's inertia and swing duration. To our surprise, a group that observed a skilled model for 60 trials showed improvements similar to that of a physical practice group. Two principles may explain this exploratory effect of observational learning: *internal pattern* (or *event*) *generation* and *gradual correction.* Observing a model need not be limited to the "imprinting" of a perceptual template, as often assumed; it may well involve processes of internal pattern generation, thus functioning as an externally guided form of motor imagery (Jeannerod 1994; Vogt 1994; 1995; 1996a; 1996b). Unlike in motor imagery, however, observers can detect divergences between their internal plan and the model, which can be used for gradual corrections, either immediately or when preparing the next (overt or covert) performance. Meltzoff and Moore (1994; 1997) stress that infants' imitations are seldom perfect from the start; moreover, infants gradually correct their imitative attempts in a sequence of ordered steps. Adult imitation may involve an internalization of this process and thus act as a shortcut in exploring task constraints.

Imitation as selection. For analysing the processing stages and neural pathways involved in a particular imitative behaviour, it is useful to identify the earliest indication of a specific response to the model behaviour under various display conditions. We are currently investigating the imitation of simple object-oriented hand actions. Data from one pilot study indicate that kinematic responses to shifts in the direction of a model's hand grasping one of three objects are as fast as responses to shifts of the target object's location (see Paulignan et al. 1991). Note that in such speeded response tasks the model display is mainly used as a way to select one of a (normally small) set of possible actions. Whereas B&R prefer to exclude such selective, instantly model-guided behaviour from imitative phenomena, we see no reason to do so *a priori.* To conceptualize imitation as selection in such tasks seems to imply a very small number of visually addressable dimensions of control. Accordingly, this view would become increasingly untenable if imitation extended beyond the instructed task dimension (location in our study) and incorporated other task dimensions such as grip aperture or speed and height of transport. Exactly such instant multi-dimensional visual addressing of motor control seems to be largely absent in speeded imitation tasks, and subjects' copying is reduced to the essential.

In summary, the enormous flexibility of unconstrained primate imitative behaviour appears to emerge from a variety of individually addressable visuomotor channels, or modules, which most likely involve a complex network of parietal, temporal, and frontal cortical areas (Carey et al., 1997). A detailed investigation of this neural substrate requires a suitable "taxonomy" of imitative behaviour based on experimental research, in which the hierarchical level of imitation represents only one of a possibly large number of relevant dimensions.

Indices of program-level comprehension

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Abstract: Byrne & Russon suggest that the production of action by primates is hierarchically organised. We assess the evidence for hierarchical structure in the comprehension of action by primates. Focusing on work with human children we evaluate several possible indices of program-level comprehension.

Byrne & Russon (B&R) argue that apes, like human children, are capable of program-level imitation. This type of imitation involves an appreciation of the way in which the hierarchical organisation of the model's action realises its goal. We expand on an important implication of their argument.

Following the arguments advanced by Miller et al. (1960), we assume that human beings engage in hierarchically organised, planned action. These arguments are likely to extend to the great apes. The more contentious issue, in our eyes, is whether young primates can perceive and comprehend the hierarchical structure in the planned activities of an adult so as to reproduce it when they themselves act. In this commentary, we assess evidence for such program-level comprehension. We focus primarily on research with human children.

Weak indices. One criterion for attributing program-level comprehension is the tendency to omit those details of an observed action that serve no functional purpose. However, the evidence for such a tendency among young children is questionable. Young children have often been found to persist in replicating such details, even when their nonfunctionality has been made clear (Whiten et al. 1996). Furthermore, this criterion may sometimes yield false negatives, in that there may be some utility to copying all the details of demonstrations, either because they are not fully